A CHEMICAL STUDY

OF

OILS AND FATS

OF ANIMAL ORIGIN

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OF ANIMAL ORIGIN

BY M. E. CHEVREUL

> You have to strive to be infallible without claiming to succeed
> Malebranche

Translated and annotated by Albert J. Dijkstra

Edited by Gary R. List and Jaime Wisniak

Original title: *Recherches chimiques sur les corps gras d'origine animale*

Date of original publication: 1823

Original publisher: F.G. Levrault, Libraire-Éditeur
rue de M. Le Prince no 31, Paris, and
rues des Juifs, no 33, Strasbourg

ISBN 978-2-9533244-0-2

Published by Sàrl Dijkstra-Tucker
Carbougnères
47210 St Eutrope-de-Born
France

Distributed by: AOCS Press
P.O. Box 17190
Urbana IL 61803-7190
USA
Phone: +1-217-693-4812
Fax: +1-217-693-4856
UUorders@aocs.org

TO

NICOLAS-LOUIS VAUQUELIN,

MY TEACHER

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Contributors

Albert J. Dijkstra, Ph.D. specialized in gas kinetics at University College of Wales, Aberystwyth, UK before defending his Ph.D thesis in Leyden, the Netherlands in 1965. He then worked for ICI, first in a central research laboratory in the UK, then at the ICI Holland Rozenburg Works and finally at the ICI Europa headquarters in Everberg, Belgium.

In 1978, he became involved in edible oils and fats when he joined the Vandemoortele Group in Izegem, Belgium as R & D Director. He is the inventor in a dozen patents and has published numerous articles and book chapters on edible oil processing; he has also acted as co-editor.

He was the first non-American to receive the American Oil Chemists' Society (AOCS) Chang Award (1997) and also the first to receive the European Lipid Technology Award (2002). In 2009, he was selected for the Alton E. Bailey medal of the AOCS and the Chevreul medal of the Association française de l'étude des corps gras (AFECG). Although officially retired, he continues to be active in the field of edible oils and fats as an author, editor, inventor and scientific consultant.

Gary R. List was a research chemist at the Northern Regional Laboratory (USDA) in Peoria, Illinois, from 1963-2007. His research involved edible oils, oilseed processing and fat modification. He is the author of over 310 publications and has edited 4 books on fats, oils and lipids. His honors/awards include the Bailey Medal, Fellow and Award of Merit of the American Oil Chemists' Society (AOCS), and the Chang, Macy, and Division Lecture Awards of the Institute of Food Technologists (IFT). He is also the recipient of the Outstanding Achievement Award of the United Soybean Board and the European Lipid Technology Award (2009). While retired, he continues to be active in society work and consulting for the oilseed industry.

Jaime Wisniak, Ph.D. was born in Santiago, Chile. He has a degree in Chemical Engineering (1957), Pontificia Universidad Católica de Chile (PUC); PhD in Chemical Engineering, Purdue University, (1960); B.Sc. in Chemistry Ben-Gurion University of the Negev (BGU), Israel (1987); and B.Sc. in Life Sciences, BGU, Israel (1992). Between 1960 and 1970 he was a member of the Faculty of Engineering at PUC, where he served as Head of the Department of Chemical Engineering, Director of the School of Engineering, and Director of the Plan of Development. In 1971 he joined the Department of Chemical Engineering of BGU.

At BGU he has served as Head of the Department of Chemical Engineering, Dean of the Faculty of Engineering Sciences (3 times), and

Vice President for R&D. He is the recipient of several awards, including the "Ismael Valdés Valdés" award for the best engineering graduate, Chilean Institute of Engineering; E. D. Bergman Prize for Applied Research (in the presence of the President of Israel); Benjamin H. Swig Chair in Chemical Engineering; Purdue University “Distinguished Engineering Alumnus"; Doctor Scientiae et Honoris Causa, Universidad Católica de Chile; Outstanding Chemical Engineer, Department of Chemical Engineering, Purdue University; Visiting Chair, Banco de Bilbao y Vizcaya, Universidad Complutense, Madrid; and Toronto Prize for Excellence in Research. He is a member of the Israel Institute of Chemical Engineers; American Institute of Chemical Engineers (Fellow); American Chemical Society and Science Honorary Sigma Xi. He is the author of 6 books (one of them on the Chemistry and Technology of Jojoba Oil), 7 patents (uses of jojoba oil), and more than 370 papers in international scientific journals, in his areas of interest: catalysis, kinetics, thermodynamics, vegetable oils, and historiography.

Preface

In 1811, when Michel Chevreul began his research, the chemical nature of fats, oils and lipids was unknown. Some 12 years later he published his classic work based on a series of publications that appeared in *Annales de chimie* during the period from 1813-1823. This work entitled: "*Recherches chimiques sur les corps gras d'origine animale*" is of interest not only for establishing the chemical nature of fats but also from a historical point of view by giving an insight into the mind of one of the premier organic chemists of the early 19th century. Berzelius commented that Chevreul's work should serve as a model for young chemists wishing to do research in any field of chemistry and went on to say that Chevreul's investigations were the most complete and best executed series of experiments in all of chemistry.

Von Liebig also had glowing comments about Chevreul's work: "Chevreul has shown the connection between the saponification products and their mode of formation and that work was the starting point of all subsequent research and the basis for all prevailing methods of analysis and investigations of organic materials." We must thank Chevreul for the beautiful principles underlying every organic investigation. Other contemporaries declared: "Chevreul's work is a masterpiece."

It is therefore most surprising that this masterpiece has never been translated into English. It was reprinted in 1825, in 1886 on the occasion of the author's 100th birthday and again in 1986. It has also been published as a pdf-file and can be accessed via http://books.google.com but all these publications are in French, which limits their accessibility; a translation into English is therefore long overdue. Accordingly, the American Oil Chemists' Society has taken the laudable initiative of distributing our translation of this masterpiece on the occasion of its own centenary.

However, translating this book is complicated not only because it is written in 19th century French but also since it requires knowledge of contemporary 19th century chemistry. Dr Albert Dijkstra has responded to both of these challenges by translating the text into a more modern and readable form and by annotating the work in the light of modern chemical knowledge. The translator and the editors hope the reader will enjoy this remarkable contribution to the history of lipid chemistry.

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Héliogr. Dujardin.

M. E. CHEVREUL
31 Août 1886.

E Chevreul

Imp. Eudes.

Biography of M.E. Chevreul[*]

Michel Eugène Chevreul (1786-1889) is an excellent example that old age is not necessarily an impediment to a fruitful productive life. He lived to be almost 103 years and to the very last minute was very active in French science. His contributions to the chemistry of fats and to the chemistry and physics of color were fundamental to the understanding of the principles that govern them. His discovery of the chromatic circle put fabric dyeing on a scientific basis that led to the flourishing development of tapestry, and his discoveries related to fatty materials such as stearin put the candle industry on the road to its modern development. Chevreul established the nature of fats and their saponification, and isolated and described many of the commonly known fatty acids.

His name is not one that appears in standard books of chemistry and physics. No reaction or theory carries his name but his fundamental and applied research stands behind many common products like drying oils, soaps and candles. His work signals the understanding of the chemistry of fats.

When Chevreul was old enough to go to school, all educational institutions had been disbanded, and for five years his parents had to have recourse to private teachers. In 1803 he moved to Paris to pursue his chemical interests in the laboratory of Louis Nicolas Vauquelin (1763-1829) at the Muséum d'Histoire Naturelle. His first activities under Vauquelin were the study of the coloring materials present in natural products. Between 1807 to 1811 he was able to isolate brazilin from brazilwood, hematin from logwood, quercitrin from oak bark, luteolin from dyer's wood, and morin from fustic.

Chevreul was elected to the Académie des Sciences in 1826 and in 1830 he was appointed to the chair in chemistry at the Muséum, in replacement of Vauquelin. Chevreul continued to work and attend the Académie meetings until he was 102. On the jacket of Bouchard's book it is written that Chevreul witnessed in his own country four kings, two emperors, three republics, and four revolutions. When he was about eighty-five years old, instead of adding some of his professional and academic titles to his name on the title pages of his publications, he wrote simply "*M. Chevreul, doyen des étudiants de France*." He read his last communication to the Académie in May 1888. He died April 9, 1889, five months before the Eiffel tower was inaugurated. His state funeral at the Cathedral of Notre Dame attracted thousands of people who massed near the church in spite heavy rains. Chevreul's ashes are buried at the cemetery of l'Hay.

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[*] Taken from Wisniak, J., Michel Eugène Chevreul, *Educ. Quím.*, **13**(2), 133-141 (2002).

Chevreul was a pioneer not only in organic chemistry but also in many other fields. The results of his experimental work were not sufficient and his curiosity led to his contributions in the areas of dyeing, color theory, and psychology. Many of the questions that he asked himself could not be answered experimentally, but only by patient efforts in the library and long meditations. His appointment, in 1824, as director of dyeing at the *Manufacture Royale des Gobelins*, the national tapestry works of France, marked a new direction in his career. Chevreul realized immediately that dyeing was done according to recipes and that to improve the process it was necessary to put it on a scientific basis. He set up an experimental program to determine the character and properties of fibers, the mutual actions occurring between fibers and acids, bases, and salts, between fiber and organic dyes, and between combinations of these. He also analyzed the influence of mordants on the tone and stability of colors, bleaching, and preservation of colors, and the effect of water quality on the finished material. In order to solve the problem of the definition and representation of colors Chevreul proceeded to define a chromatic circle in which, out of three pigments of red, yellow, and blue, he was able to realize almost fifteen thousand shades or tones.

Chevreul's investigations of the chemistry and composition of fats and oils constitute his most remarkable scientific contribution. He was led into this subject in 1811 when Vauquelin asked him to analyze a sample of a potassium soap made from pig fat. As an initial step Chevreul prepared a very dilute aqueous solution of the soap and observed that shiny crystals separated from it (*matière nacrée*). Acid treatment of this fraction of the soap, followed by crystallization in alcohol, yielded a solid fatty substance that possessed the properties of an acid, a property that was in contrast to the neutral fat from which the soap was derived. He named this fatty substance *margarin*. In a later work he changed the name margarin to *margaric acid*. Margaric acid (although misidentified as a pure acid) was the first of the several fatty acids that he was to isolate from natural fats. In a following paper Chevreul reported that from the dissolved part of the soap he had obtained a second acidic product, this one of a fluid character. He named it *fluid fat*, later redesignating it *oleic acid*. Having determined the results of the saponification process, Chevreul went on to determine whether the products of saponification were originally present in the fat. His results indicated that the fat was neutral before saponification and that after combination with alkali it produced the solid and liquid fatty acids and the sweet principle of Scheele. In a later work Chevreul named the sweet principle *glycerin*. In a few words, Chevreul elucidated the process of the formation of soap and showed that fats are combinations of acids with glycerin.

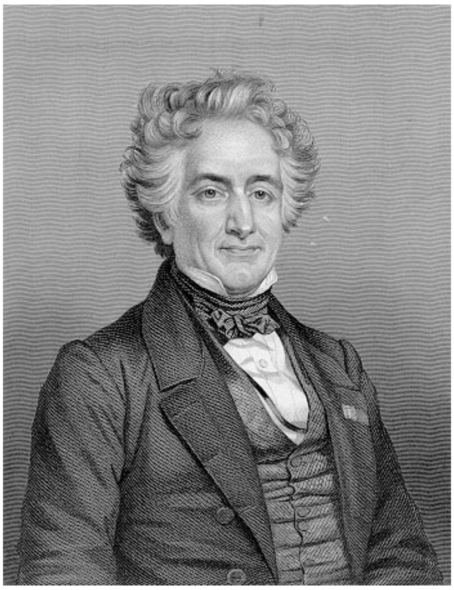
Chevreul studied the saponification process using a variety of bases; he saponified fats from all available sources, including man, wild and domesticated animals, oils of vegetable origin, and the crystalline substance present in biliary calculi (cholesterol). Such origins are revealed in the names he coined for the new acids: *butyric* (butter); *capric, caproic* (goat); *delphinic* (dolphin); *phocenic* (porpoise); etc. His investigation of the nature of spermaceti led him to purify cetin by repeated crystallization. Saponification of spermaceti led him to prepare cetyl alcohol.

Chevreul utilized his discoveries to develop a system of nomenclature for fats and derived products. The chemical substance in biliary calculi he called *cholesterin;* spermaceti was to be *cetin,* the solid fat principle and the liquid fat principle were to be *stearin* and *elain* (oil; eventually he would change this name to *olein*). The acid from saponified spermaceti was named cetic acid and the terms margarates, oleates, and cetates, were to be the generic names for the soaps, which these acids formed with bases. His copious research on the subject eventually led to a 500-page book summarizing the state of the art in the chemistry of fats.

Chevreul's experiments on the saponification of fats led him to believe that the product could be used for manufacturing new and improved candles: together with Joseph-Louis Gay-Lussac (1778-1856) they financed the building of a factory for the manufacture of stearic acid by treating fats with alkali or acid. Although this venture was a commercial failure, the further development of the French industry for the manufacture of candles from fatty acids is based on Chevreul's work. In recognition of these merits, Chevreul was awarded in 1852 the Marquis d'Argenteuil prize for the encouragement of national industry (12 000 francs). The jury of the International Exposition of Paris of 1855 also recognized these merits and awarded him a grand medal of honor.

Besides chemistry and physics, Chevreul was also interested in psychology and the history of science. In 1853 he was head of a committee appointed by the Académie to inquire into the phenomena of the divining rod and the pendulum, which had been the subjects of recent memoirs to the Académie and were thought to be the result of the organoelectricity, which resided in humans. Chevreul experimented with the pendulum and explained it as the result of expectant suggestion; the swinging pendulum was a case of autosuggestion: as long as you believed the movement possible, it occurred. Chevreul's incursion into psychology led him to write a book on scientific method where he stated that he always sought to establish general methods and principles and was never satisfied with making individual discoveries. He claimed that one of the principal functions of experiments was the testing of the validity of preliminary conclusions based on the study of natural phenomena. All generalizations should be submitted to rigorous verification by experiments and observation.

In 1866 Chevreul published the first volume of his history of chemical knowledge, which was meant to include four volumes. In the first volume he discussed the purpose and field of chemistry, its relationship with other sciences, with natural history and with life itself; the classification of the sciences; and scientific abstraction versus art and literature.



M.E. Chevreul at 50 years of age; lithograph by Maurin; engraving by Conrad Cook

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Foreword by the translator/annotator

When working on a text, a translator should try to keep as close to the original as possible and try to make sure that people reading the translation get an identical impression as those able to read the original. If the author expresses himself ambiguously, this ambiguity should be maintained. Even mistakes should be preserved, although the translator can insert a footnote pointing out this mistake and thereby avoid being blamed for it.

This means that there are two kinds of footnotes: those by the author and those by the translator. The author numbered his footnotes per page and started again with (1) on every new page. Accordingly a distinction between these two kinds of footnotes will be introduced by keeping the author's footnotes on the page where they arise and identifying them by symbols like: *, †, ‡ and §. Footnotes by the translator/ annotator will be numbered consecutively and listed in numerical order at the end of each chapter as endnotes.

Like authors, languages also differ in style. Some aim to be very precise whereas others are less finicky. Some glory in being ornate while others prefer to avoid flowery expressions. Accordingly, translating an ornate sentence literally into a language that prefers simplicity amounts to rubbing the reader up the wrong way. He won't like it since what he is forced to read is evidently translated. So whereas the translator should aim to maintain the style of the author, he (or she) should also adapt his style to the language he is translating into.

Accordingly, the title of the present work could be translated into modern English as: *The Chemistry of Animal Fats.* That is much shorter and more direct than a more literal translation such as *A Chemical Study of Oils and Fats of Animal Origin.* Moreover, the left page header uses a running title *LES CORPS GRAS D'ORIGINE ANIMALE,* presumably because there was no room for the full title. So a choice had to be made: For the full title of the book, the long translation was chosen since it may remind people of the original. The running title chosen is ANIMAL OILS AND FATS.

Editors face a different task. When they edit a book consisting of contributions from different authors, their prime task is to avoid overlap and ensure some degree of internal consistency. However, when editing a translation, their role is more limited. They can supply background information and comment on and/or suggest further endnotes and assist the copy editor in his efforts to maintain internal consistency.

What about a translator who works on a book that was published in 1823 and is of the greatest historical significance? In that case, I think it is the moral duty of the translator/annotator to make sure that above all, the historical significance of the book is highlighted. Consequently, he should feel free to modernize the style of writing by for instance chopping up sentences that in the original cover more than half a page, and cut out some verbosity. He should introduce modern technical jargon and explain this in an endnote. And above all, he should concentrate on making sure that the scientific achievements of the author are well explained and put in their historical context.

Palmitic acid (C16:0 or hexadecanoic acid) was discovered by Chevreul. Because it formed nice pearly crystals, he called it "acide margarique" after the Greek word for pearl: μαργαρίτης. Nowadays, margaric acid refers to a different fatty acid: heptadecanoic acid (C17:0). Accordingly, the name 'palmitic acid' will be used for the acid the author refers to as 'acide margarique'.

Similarly, ancient names of various chemical reagents will be replaced by their current, more systematic names. In his experiments, Chevreul regularly uses "massicot" and I wonder just how many Frenchmen today know that this compound is actually lead oxide, which they would now refer to as "oxyde de plomb". So, although there is an equivalent ancient word in English, I use 'lead oxide', since this is the term in current use.

In another respect, the author was very modern in that he used the metric system of measurement as adopted by the French government on 7 April 1795. He uses degrees centigrade which he just calls 'degrees'; they have been translated as °C. He expresses densities as grams per milliliter but does not mention this unit of measurement. Where the author mentions a unit, this has been mentioned in the translation. If he has not mentioned the unit concerned, it has been added in brackets in the translation. If he describes properties in a different way than is customary today, an endnote provides the conversion.

When trying to understand what the author meant, I have made extensive use of the worldwide web. In fact, I would not have been able to understand many of his expressions without access to the web. At a certain stage, Chevreul mentions "potasse à l'alcool" which at first sight looks like an alcoholic solution of potassium hydroxide. However, when consulting the web, I learned that potassium hydroxide was produced by the causticization of a solution of potassium carbonate according to:

$$K_2CO_3 + Ca(OH_2) \rightarrow 2\ KOH + CaCO_3\downarrow$$

If then the supernatant solution of potassium hydroxide is evaporated to dryness, it tends to absorb carbon dioxide from the air and thus yield an impure product. The way to get a less impure product involved mixing the concentrated potassium hydroxide solution with alcohol. This led to the formation of two phases: an upper alcoholic phase with reasonably pure potassium hydroxide and a lower, aqueous phase with potassium carbonate and other salts. In other words, what I originally intended to translate as 'alcoholic solution of potassium hydroxide' turned out to contain no alcohol. This is just an example of getting to grips with the subject and of arriving at a solution. For the annotator, doing this has been a constant source of enjoyment, just as appreciating the many contributions the author made to lipid chemistry.

In one way, the layout used by Chevreul or his publisher was extremely modern: he numbered his sub-sections just as US Patent specifications started to do only a few years ago. However, Chevreul had a reason to do so since he used these numbers to refer to these sub-sections; I have therefore kept these numbers. Another way in which the author facilitated browsing through his book was by having side notes printed in the margin. I found them useful so I have retained them as well.

Because this translation has been published by printing-on-demand, I was also responsible for the copyediting. To this end and at the instigation of AOCS Press, I have made extensive use of *The Chicago Manual of Style* but at the same time, the style of the original work has been maintained whenever possible.

Finally, I want to express my thanks to Gary List for taking the initiative of commissioning the English translation of the first book ever published on lipochemistry; to Jaime Wisniak for suggesting background literature, the inclusion of an index and ways to improve my first efforts at translating this monograph; and to the AOCS Press for fulfilling a public service by distributing it. Above all, I want to express special thanks to my wife Liz for undertaking the mammoth task of correcting my translation and polishing my English, which for me still is a foreign language, just like French. Her contributions have been very necessary, highly professional and extremely valuable.

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INTRODUCTION

Inconvenience of presenting several investigations of the same subject in a series of reports

When undertaking a chemical research project that is likely to expand, a scientist will almost always start with a random sequence of observations. So when reporting the results in the order in which he found them, he will be following a course that he has not consciously chosen. If on the other hand, he could have postponed the presentation of his findings, he would have been able to oversee them as a whole and present his findings in the order he felt to be the most suitable. But now he has to keep repeating himself, either to correct what he said before, to complement his first observations or to emphasize certain aspects that he had originally given little attention. Then there are also the incidental experiments that are nevertheless necessary to elucidate the main research or to substantiate the conclusions drawn from it. There is also the inconvenience of having to give certain substances a circumlocutory designation because we do not yet know enough about them to be able to give them a name. From all this you will realize that most readers will find reading a number of articles on the same subject very tiresome[1] and will therefore tend to take an unfavorable view of work resulting from long observations and numerous experiments.

There are people who are very severe in their judgment of someone who has carried out many experiments on the same subject[2]. They do not forgive him the mistakes he has made and instead of thanking him for clearing up the obstacles and paving the way, they accept what he has done with indifference as if it were the natural result of the time he devoted to his work. They reserve their praise for the man who in a short period of time satisfies their curiosity by presenting a variety of different studies containing just a few interesting facts that can be easily grasped in isolation, since they are not put together to create a coherent system, which is something which always calls for more effort and study to understand and appreciate at its true value. The people we are talking about are not aware that discovering striking but isolated facts is in general much easier than discovering the secondary facts that link them together, since the former are often stumbled on by pure chance. It is when you try to link up these chance observations and arrive at a distinction between the primary facts and secondary consequences[3] that obstacles start mounting up and time seems to pass at a frightening speed for the researcher who cannot see an end to his endeavors. Although this is hard and painstaking work, it nevertheless has indisputable advantages for the advancement of science and for the researcher himself, who finds many opportunities to verify the conclusions he has drawn from earlier experiments.

Scientific advantages of a detailed investigation of a subject

People say that chemistry consists of facts but there is more to it than just facts. When providing general definitions or classifying compounds according to similar or different properties, known facts must necessarily be interpreted to establish the links between them. Drawing up a definition therefore also means establishing links and assigning different degrees of importance to the various properties. This is more than simple fact-finding, although every interpretation and every definition must be based on well-established facts. Priestley has discovered a large number of important compounds. He has also determined most of their properties and he has certainly provided science with more factual data than Lavoisier. Nevertheless, without wishing to detract from the importance of this great English scientist, we can safely say that posterity attributes more importance to Lavoisier. This can only be because of the way he has interpreted the facts. What holds for the facts that form the basis of the anti-phlogiston theory[4] must also hold for facts that are yet to be discovered. Accordingly, we are of the opinion that it is better for the progress of science if we assemble as many analogous facts as possible and attempt to correlate them so as to arrive at general conclusions which transform a collection of facts into true science, rather than gathering facts on a diversity of unrelated subjects.

Advantages for the scientist of investigating a subject in detail

If you accept that it is essential to estimate the confidence limits of the experimental data, you will agree that the course we have followed is the most appropriate. If you want to determine the elemental composition of a compound you have recently discovered, various difficulties arise regarding the methods of observation used. Nobody will deny that there can be no discoveries without accurate experimentation. But the art of carrying out experiments, being of a mechanical nature, presents a variety of obstacles to overcome. The results depend on the accuracy of the means or the instruments used. Consequently, it is essential to assess the accuracy of the instruments before using them, whether they be instruments we have inherited from our predecessors or new instruments the nature of the work has obliged us to invent ourselves[5]. Therefore, the investigation of similar but little known compounds necessarily entails a determination of the accuracy of the methods of observation. The large number of experiments he carries out to get to know his oils and fats will provide the scientist with many opportunities to verify his initial observations. This proliferation of experiments will also lead him to take into account differences between the results that he would have passed over or not noticed if he had only performed a small number of experiments, and it will also enable him to disregard certain differences that struck him initially, but which were not confirmed by subsequent repeat experiments. Furthermore, by multiplying the number of angles from which analogous compounds can be looked at, the experiments that are the easiest to carry out can be used to check those that are more difficult to carry out in an accurate manner.

Our motives for studying organic compounds

When we started to study natural science, we were struck by the vagueness which then dominated organic chemistry. At the same time, we noted the wide range of applications that this branch of natural science could support in the fields of physiology, anatomy, medicine, and numerous skilled activities and crafts that aim to manufacture useful products for mankind from organic materials. These considerations have long motivated us to reflect on everything connected with the chemistry of organic compounds.

The way in which we have investigated the composition of organic compounds

We have applied ourselves to finding out all we could about the immediate principles[6] that can be isolated as such from vegetable and animal matter because *this knowledge forms the basis of organic chemistry and all its applications.* It is in this conviction that we undertook our research into natural and synthetic astringent compounds, minerals and dyes before we started to work on edible oils and fats. It was only after we had made every endeavor to isolate the immediate principles that together constitute the materials under investigation, that we tried to characterize first of all each species by its chemical properties and a range of physical properties, and subsequently to determine the relationships between these species and with the compounds that have already been described.

How we approached organic analytical chemistry

1. Concerning the reagents that are used

As we worked to achieve this goal, we also focused our attention on our research tool itself, that is to say on *organic analytical chemistry.* We tried to understand how the most common reagents work and what influence the major experimental conditions exert when these reagents are allowed to react with organic compounds. For instance, when we studied synthetic astringent compounds, we investigated the effect of sulfuric acid and nitric acid on a fairly large number of compounds. When studying dyes and the extract of woad[7] leaves, we tried very hard to understand how the salts and their immediate principles act in general on the dyes and the organic matter that they precipitate. In the description we published of our distillative autoclave, we considered several questions concerning the use of solvents in organic analytical chemistry and presented a simple method enabling these solvents to act at a higher temperature than is possible when they are heated at atmospheric pressure. Finally, our latest research has made us realize that alcohol, ether[8] and nitric acid do not generate oils and fats when acting upon various compounds containing nitrogen[9].

2. Concerning the main experimental conditions

With respect to the main experimental conditions used in organic analytical chemistry, we have noticed that the effect of heat on vegetable and animal compounds generates different results depending on whether these compounds are heated in the presence or absence of atmospheric oxygen. We have also noted that alkali acting on many of the same compounds, produces totally different phenomena, depending on whether oxygen is present or excluded. Our observations explain several anomalies presented by gallic acid, hematin, carmine, etc. when brought into contact with air and alkalis at the same time. We have also realized the influence of oxygen from the atmosphere on the nature of the products resulting from putrefaction. Finally, we arrive at the conclusion that the *decomposition products of the organic compounds that we have examined are less complicated than generally thought. This follows from our observation that we found several immediate principles in matter that has been regarded as pure species. It also follows from our consideration of the influence of air on the action of reagents.*

Our views on organic analytic chemistry will be expounded in a special monograph. However, when reporting our work, it would be ungrateful and unjust not to mention the help we have found both in the writings of our respected teacher Mr. Vauquelin and in the advice that his benevolent friendship has continually prompted him to give us over the past twenty years.

The work that we now present to the public consists of six books, which we will first discuss briefly.

BOOK I

How our research on animal oils and fats has been presented in this book

First of all, this book provides a number of definitions that we think are necessary for a clear understanding of this work. They are drawn from earlier writings and the as yet unpublished monograph mentioned above. Secondly, the book provides a detailed description of the analytical method we used to determine the elemental composition of oils and fats. This method comprises burning the sample with copper oxide, just as Gay-Lussac determined the carbon to nitrogen ratio in uric acid by burning this acid with the same oxide. We would be honored if our analyses of elemental compositions were to be regarded as a continuation of the work of Gay-Lussac and Thenard[10], and Berzelius. We are bound to acknowledge our great debt to these two French scientists who developed the method of determining the elemental composition of organic compounds.

BOOK II

This book describes all the species[11] of fatty matter of animal origin that we have investigated.

These species are described as follows:

1. *Composition of the species*

After having described the composition of the species that show some acidity in the samples that we studied, we indicate the proportion of water that results from heating that acid with lead oxide. According to the current state of knowledge, one could believe either that this water had simply been separated from the acids or that it had been produced by some of their hydrogen and the oxygen in the lead oxide. According to the first hypothesis, the acids as analyzed should be *hydrates*[12]. According to the second one, they are *hydrogen acids*[13]. In this book, we have taken the first hypothesis as our point of departure but with respect to the second hypothesis, we have also given in the Notes the composition of the fraction of the acids that combined with the lead while being heated with the lead oxide. We must admit that the volatilization of the ammonium stearate and palmitate[14] that had been prepared by a dry process whereby no water was liberated[15], favors the second hypothesis. We also add that lately we have observed quite a number of phenomena in compounds other than edible oils and fats that now look to us to be more in line with the hydrogen acids hypothesis than with the hydrate hypothesis[16].

2. *Physical properties of the species*

3. *Chemical properties that have bee observed without changing the elemental composition of the species*

4. *Chemical properties as observed in the species when it is brought into contact with other compounds or conditions that induce a change in its composition*

We felt that we should introduce this distinction between two groups of chemical properties rather than describe successively in the same book what is observed when the species are subjected to heat, light, electricity, simple reagents, acids, etc. because there is a link between the properties of a certain group that would be lost if the chemical properties were simply presented one after the other. In fact, it is clear that the properties belonging to the first group are the only ones that can be considered to be an essential part of the nature of the substance because they stem from *the kind of nature* that remains unchanged by the circumstances under which we observed the phenomena that result from those properties. The properties of the second group also pertain to *this nature* but they only become evident when it is changed in such a way that it is in fact the elements of the species that react, either on their own or by giving rise to products that are less complex than the species themselves. For example, when water combines with lime[17] and salts, it still acts like water and its nature undergoes no change. But if water vapor is passed over red-hot iron, it decomposes and no longer acts as water but like oxygen[18].

We regret all the more that we have not had time to study the effect of chlorine and iodine on oils and fats since some phenomena we observed when bringing palmitic acid into contact with chlorine looked extremely interesting[19]. We also regret that we have not determined all the effects that sulfuric acid and especially nitric acid have on oils and fats; we had only expected to find effects that would be characteristic of only a small number of compounds. We would have liked to extend our experiments to confirm our suspicion that an acid that had formerly been prepared by Vogel by treating 'axonge'[20] with nitric acid is identical to the acid that we obtained from all species of oils and fats in which the atomic ratio of hydrogen to carbon is the same or almost the same as in 'hydrogène percarburé'[21]. If so, this acid would have the same relationship to oils and fats that produce it, as oxalic acid has to substances that release significant quantities of the latter when treated with nitric acid.

5. *Occurrence of the species*
6. *Preparation of the species*
7. N*omenclature of the species and synonyms*
8. *History of its discovery and of the work this discovery has led to*

BOOK III

Now that the main properties of the species of oils and fats have been described, we present appropriate methods to prepare them in the state in which we have studied them. We explain our methods and in a table, we summarize all the steps that may be needed to isolate the saponification products from the most complex fatty matter.

We preferred to devote a separate book to the preparation of most of our species rather than including it in the previous book since our methods are novel and involve a large number of steps

BOOK IV

Here we discuss the animal fats that comprise several immediate principles and fats from human cadavers.

BOOK V

Having now established the composition of saponifiable oils and fats as well as that of their saponification products, we will now try to verify our analyses by comparing the saponifiable moieties in oils and fats with the saponification products on the basis of their elemental composition. Subsequently, we will consider saponification with respect to alkaline bases in general and more in particular with respect to the proportion of the alkaline base that can saponify a given weight of fat.

BOOK VI

This book presents general remarks under different headings. After having discussed the current state of knowledge about oils and fats before we started our work, we consider the immediate principles of which these oils and fats are composed, more or less in the order in which we carried out our investigations. We explain the *principle* to be used to establish what amounts to a compound in organic chemistry. This principle can be seen as the shortest possible summary of our analytical research. It has been our guiding principle for a long time and we hope it will have a most propitious influence on the progress of analytical chemistry by providing young chemists with a *criterion* they have had to manage without until now. Then we will summarize the most general conclusions that can be drawn from our research: 1. with respect to the effect of solvents on the salts of fatty acids; 2. with respect to saponification. We will point out several applications of our work and finally, we will speculate on the immediate principles of which saponifiable oils and fats are composed.

Nearly all the research in this book has been presented to the Academy of Science[22] in the form of reports in chronological order, which is very different from the order in which our findings are presented in this monograph. During the three years that have passed since this book was written, we have done our utmost to make it as worthy as possible of scientists' attention. When more recent work made us suspect that the accuracy of certain experiments could be improved, we did not hesitate to retrace our steps. Accordingly, most of our elementary analyses have been repeated several times. Since we want above all that the truth be known, we openly explain the difficulties we had to overcome and nowhere do we try to hide any gaps that need be filled to make our work complete. Those who would like to continue this work will sense the truth of what we put forward and those who would like to apply it, be it in the arts or in science, will not go far wrong if they carefully read and digest what we have reported.

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[1] Nowadays, copy-editors would almost certainly delete this negative publicity but fortunately, they did not yet exist in 1823 so that the honesty of the author has been preserved.

[2] Here the author refers to himself and his scientific method.

[3] These secondary consequences as elaborated by the author are in fact his main contribution to the understanding of the chemistry of oils and fats.

[4] In the 18th century, chemists supposed that all combustible bodies contained a substance that was released in combustion; they called this substance "phlogiston". Antoine Laurent Lavoisier (1743-1794) demonstrated that combustion leads to a weight gain and prepared oxygen by decomposing mercuric oxide. He thereby refuted the phlogiston theory.

[5] Here the author refers to the 'distillative autoclave' he describes in more detail on the next page.

[6] This is the first time Chevreul introduces the concept of *principe immediate*; from his definition in Book I Chapter 1, sub-section (5), the term *structural moiety* can be arrived

at as the most likely description. However, the original term 'immediate principle' will be used.

[7] A yellow-flowered plant of the cabbage family, also known as *Isatis tinctoria,* which was widely grown in Britain as a source of blue dye, which was extracted from the leaves after they had been dried, powdered and fermented. (Oxford English Dictionary). See also: M.E. Chevreul, Analyse chimique de l'*Isatis tinctoria* et de l'Indigofère, *Ann. Chim.* **68**, 284-312 (1808).

[8] The author uses the term "éther sulfurique" but according to a book (Charles Moureu, *Notions Fondamentales de Chimie Organique*, Gauthier-Villars, Paris, 1913), which my father used when studying chemistry, this term is synonymous with "Éther ordinaire" or diethyl ether. However, some people held the opinion that the sulphuric acid formed part of the ether and made a distinction between sulfuric ether and nitric ether.

[9] Presumably, some fellow scientists had carried out a few experiments and generated a substance that had a fatty feel. By refuting that any oil was made, the author also highlights the shortcomings of this approach to science.

[10] Chevreul spells this author's name as Thénard, with an acute accent, but there are also authors who omit the accent. When I queried this with Jaime Wisniak, he pointed out that Paul Thenard, son of Louis-Jacques baron Thenard (1777-1857), spells the family name without an accent and he suggested we follow this example.

[11] In endnote 2 on page 4, an explanation is given of the background of the use of the word 'species'. In practice, it often means the same as 'compound'.

[12] The author distinguishes between *hydrates* and hydrogen acids. Sulfuric acid is an example of a hydrate since it can be regarded as hydrated sulfur trioxide just as its salts can be regarded as a combination of a metal oxide and sulfur trioxide. Hydrogen chloride on the other hand, is a hydrogen acid since it contains no oxygen but for quite some time, it was considered to be a compound of oxygen and an undiscovered element, *muriaticum*. Acids had been associated with oxygen since Lavoisier. In German for example, oxygen is called Sauerstoff, which translates as 'acidity matter'.

[13] They could be hydrogen acids but the hydrated acids also contain hydrogen that could react with the oxygen in the lead oxide. In the light of current knowledge, the author's conclusion is not correct, but we should not forget that we now think in terms of hydrogen ions being the cause of acidity. It was Humphrey Davy (1778-1829) who introduced this concept since all acids yielded molecular hydrogen on electrolysis.

[14] Chevreul uses the term "margarate d'ammoniaque", but as explained in the Foreword, the term maragaric acid is now used for heptadecanoic acid (C17:0).

[15] We would now write this reaction as: $RCOOH + NH_3 \rightarrow NH_4(RCOO)$ and indeed, no water is liberated when ammonium soaps are formed from ammonia.

[16] For a chemist, these were exiting times. Here the author concedes that he changed his mind with respect to acids. Berzelius adopted the new views by 1820.

[17] According to the reaction of calcium oxide (lime) with water: $CaO + H_2O \rightarrow Ca(OH)_2$ forming slaked lime, water does not stay intact but reacts. Heating this slaked lime causes the reaction to proceed in the opposite direction and thereby liberate water. This may well be the reason why Chevreul assumes the water does not react.

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[18] Both water vapor and pure oxygen react with iron under formation of iron oxide, so water and oxygen must have something in common.

[19] Allowing iodine to react with fatty acids would have revealed a difference between saturated and unsaturated fatty acids and in a later stage, between monounsaturated fatty acids and fatty acids having more than one double bond.

[20] In French, the word 'axonge' refers to a fat that is somewhat softer than lard or tallow and a Google Advanced Scholar Search provides the information that lard is used for food and axonge for ointments. It also refers to a patent (this turns out to be U.S. Patent No. 2,51,304) that discloses a process for the randomisation of lard.

[21] A Google Advanced Scholar search for 'hydrogène percarburé' yields a single hit: the current work, which is also the only place where the word 'percarburé' has been used. Chevreul uses it again in sub-section (480) when discussing cetyl alcohol and comparing the water content of cetyl alcohol with that of diethyl ether and ethanol. In that sub-section, he gives the molecular formula of his 'hydrogène percarburé' as $(CH_2)_n$. Accordingly, it will be translated as ethylene.

[22] When he wrote this, Chevreul was not yet a member of the French Academy of Science. He had applied for membership in 1816 but Joseph Louis Proust (1754-1826) was elected instead. When the latter died, Chevreul was elected to succeed him and so became a member on 9 August 1826. He was to preside over the Academy in 1839 and 1867.